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# From Asia to Europe? Where Could the Geographical Place of Origin of *Polymerus (Pachycentrum) carpathicus* (Horváth, 1882) (Hemiptera: Miridae) Be?

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This paper presents the first record of a rare species of Miridae, *Polymerus (Pachycentrum) carpathicus* (Horváth, 1882), in Poland. A broad analysis of its occurrence was conducted, which was based on modelling its potential ecological niche using past and future models, which enabled new and valuable information about the potentially suitable habitats and its possible range of distribution as well as its climatic preferences to be identified. The results of the research indicate that *P. (P.) carpathicus* prefers habitats in highlands and mountains. This species probably came to Europe from Asia via a postglacial migration and the disjunctive range that characterises *P. (P.) carpathicus* may be due to a lack of data. Additionally, the key to identifying the Polish species from the subgenera *Pachycentrum* and *Polymerus* and maps of their distribution in Poland are also presented.

**Key words:** Biodiversity, Dispersion, Distribution, Niche modelling, Plant bugs.

## BACKGROUND

The genus *Polymerus* Hahn, 1831 belongs to the family Miridae, the subfamily Mirinae and the tribe Mirini. Until recently, almost all of the *Polymerus* species from the Eastern Hemisphere (a few species were described but without any subgeneric assignment; in the case of the Western Hemisphere, some of the subgeneric structure of the genus was not developed) were placed into one of two subgenera that differ by their body colourations – almost entirely black into *Polymerus* Fieber, 1858 and with large yellow spots into *Poeciloscytus* Hahn, 1831. As a result of the comprehensive revision that was prepared by Gapon (2014), it became clear that the nominative subgenus

is heterogeneous in its composition and is paraphyletic within the confines of the Eastern Hemisphere fauna of the genus. Therefore, three species of the nominative subgenus, which have unique features in the structure of the male genitalia, were transferred into the newly created subgenus *Pachycentrum* Gapon, 2014. These species are *Polymerus (Pachycentrum) carpathicus* (Horváth, 1882), *P. (P.) nigrita* (Fallén, 1807) and *P. (P.) unciniger* Gapon, 2014 and, among them, only *P. (P.) nigrita* has been found in Poland to date.

During the field studies that were conducted by the second author, individuals representing *P. (P.) carpathicus* were found in Poland for the first time. This species occurs in both Europe and Asia. However, based on the available data, its range seems to be disjunctive



(Gapon 2014). Representatives of this species are hygrophilous, phytophagous, monophagous, have one generation a year and overwinter as an egg (Wagner and Weber 1964; Wachmann et al. 2004). They feed on *Galium boreale* L., which occurs in the temperate and subarctic zones of the entire Northern Hemisphere. *Galium boreale* grows in both wet meadows and semi-dry grasslands. It has also been found in sparse pine or oak forests (Oberdorfer 2001; Gubanov et al. 2004).

Unlike other representatives of the genus *Polymerus*, *P. (P.) carpathicus* is not often localised and when it is, only from a specific type of location (mainly mountainous areas). New data on the distribution of this species encouraged us to conduct a broader analysis of its occurrence. Therefore, we decided to perform modelling of its potential ecological niche using past and future models. In this way, we wanted to determine the primary dispersion area of this species and to find out how its range might change under the influence of climate change.

Additionally, we present the key to identifying some of the species from the subgenera *Pachycentrum* and *Polymerus*, which are represented in Poland along with maps of their distribution in the country.

## MATERIALS AND METHODS

### Occurrence data used in modelling

The occurrence data were based on a review of the available scientific literature (from 1990 to 2018). Geographic Distance Matrix Generator 1.2.3 was used to calculate the geographic distance between the designated localities (Boria et al. 2014; Ersts 2016). Sites that were spaced closer than 10 km from each other were removed in order to reduce any inherent geographic biases (effect of spatial autocorrelation). Overall, 87 unique occurrence localities were compiled for the representatives of *P. (P.) carpathicus*. All of the localities were georeferenced using Google Earth Pro 7.3.2.5776 (Google Inc. 2019; <http://www.google.com/earth/index.html>) (the coordinates for the localities were collected in decimal degrees, datum: WGS84). All of the occurrence localities that were used in the Maxent model are listed in table S1.

### Environmental predictors, ecoregions and climate classification

Our study was based on 19 current bioclimatic variables obtained from the WorldClim 2.0 dataset (Fick and Hijmans 2017; <http://www.worldclim.org>) and the digital elevation model (DEM), which

was downloaded from the Global Land One-km Base Elevation Project (GLOBE) (GLOBE Task Team and others 1999; <http://www.ngdc.noaa.gov/mgg/topo/globe>). Moreover, downscaled paleoclimate data for the Last Interglacial (LIG; ~120 000–140 000 years ago), the Last Glacial Maximum (LGM; between 26 500 and 19 000–20 000 years ago) and the Mid-Holocene (about 6000 years ago) were obtained from the WorldClim 1.4 dataset (Hijmans et al. 2005). The influence of global climate change on the potential distribution of *P. (P.) carpathicus* was estimated for two different periods (2050 and 2070) and for four future representative concentration pathways (RCPs) (+ 2.6, + 4.5, + 6.0 and + 8.5 W/m<sup>2</sup>). The average values of the modelling results for the eight future climate scenarios came from the Coupled Model Intercomparison Project Phase 5 (CMIP5): BCC-CSM1-1, CCSM4, GISS-E2-R, HadGEM2-AO, HadGEM2-ES, IPSL-CM5A-LR, MRI-CGCM3 and NorESM1-M. A spatial resolution of 60 arc seconds (~2 km<sup>2</sup>) for the continental models was selected (downloaded from WorldClim; 30 arc-seconds spatial resolution grids were interpolated to a 60 arc-seconds spatial resolution). All of the maps were prepared in QGIS 3.8 (QGIS Development Team 2019; <http://www.qgis.org>) using the WGS84 datum and EPSG: 3395 (World Mercator).

To determine which main plant communities *P. (P.) carpathicus* is associated with, terrestrial ecoregions as modified by The Nature Conservancy (TNC – an American charitable environmental organisation) were used, based on Bailey (1995), Olson and Dinerstein (2002) and Wiken (1986).

The climate preferences of *P. (P.) carpathicus* were defined based on the Köppen-Geiger climate classification system (Peel et al. 2007). The sites where the species occurred were plotted on a raster with the climate classification data and the raw data was obtained. The resulting rasters from Maxent were also plotted on a raster of the Köppen-Geiger climate classification using SAGA GIS 7.4.0 (Conrad et al. 2015; SAGA Development Team 2019).

A Spearman rank correlation test was performed in the R software platform (version 3.5.3) (R Core Team 2019; <http://www.R-project.org>) using the Rattle package (version 5.3.0) (Williams 2011) in order to eliminate any variables that were highly correlated ( $r \leq 0.75$ ). Variables without any significant contribution to the model were removed.

### Ecological niche models

In order to model the *P. (P.) carpathicus* niches and distribution, Maxent (version 3.4.1; <http://www.cs.princeton.edu/~schapire/maxent>) was used – a

machine learning software that is based on a maximum entropy algorithm (Phillips et al. 2006). While the default settings in Maxent may not produce the best predictions (Merow et al. 2014; Kumar et al. 2014a b; Samy et al. 2016; Chłond et al. 2019), a different combination of feature types (auto features or linear, quadratic and product features together (LQP)) and regularisation multiplier values (ranging from 0.5 to 1.75) were used (Table S2). The models were evaluated using the sample size corrected Akaike's information criterion (AICc and  $\Delta AICc$ ) (measures of the relative quality of models for a given dataset; calculated using ENMTools (Warren et al. 2010)), the area under the receiver operating characteristic (ROC) curve (AUC) (the performance of the model and the weight of omission and commission errors), as well as the partial area under the ROC curve (pAUC) (calculated using Niche Analyst 3.0 (Qiao et al. 2015)) (Table S2). Moreover, any models that resulted in biologically nonsensical curves (*i.e.*, highly jagged or multimodal) were removed or ranked low.

A bias file was implemented in Maxent modelling to weigh the selection of the background points to account for the sampling intensity and any potential sampling bias. A bias grid file was created in SAGA GIS and all distribution records of *P. (P.) carpathicus* were weighted by a Gaussian kernel with a standard deviation (SD) of 200 km (using the kernel density estimation). The resulting grid was then scaled to have a minimum value of 1 and a maximum value of 21 (using grid normalisation) (see Elith et al. 2010; Syfert et al. 2013).

The dataset was randomly split into 75% training and 25% test points and a 10-fold cross-validation was performed (Phillips et al. 2006; Phillips and Dudík 2008). The logistic output of Maxent with prediction values from 0 (unsuitable habitat) to 1 (optimal habitat) was selected.

Ultimately, the following variables were used: annual mean temperature (Bio01), isothermality (Bio03), mean temperature of wettest quarter (Bio08), precipitation of driest month (Bio14), precipitation of warmest quarter (Bio18) and a terrain elevation model (DEM).

## Maps and photos

The maps of the occurrence of the insects in Poland were obtained using MapaUTM v5.4 software (<http://www.heteroptera.us.edu.pl/mapautm.html>).

To prepare high-quality photos that would enable advanced processing (obtaining a uniform background, easily mounting the parts of the images), the specimens were glued on to transparent entomological glue boards

and then cleaned with a delicate brush. The colour images of the insects were captured using the following equipment: Leica M205C (stereomicroscope), Leica LED5000 HDI (high diffuse dome illumination), Leica DFC495 (camera), Leica application suite 4.9.0 (software), Image Composite Editor (panoramic image stitcher) and Adobe Photoshop CS6 graphic editor.

## RESULTS

### Evaluating the model and the importance of the environmental predictors

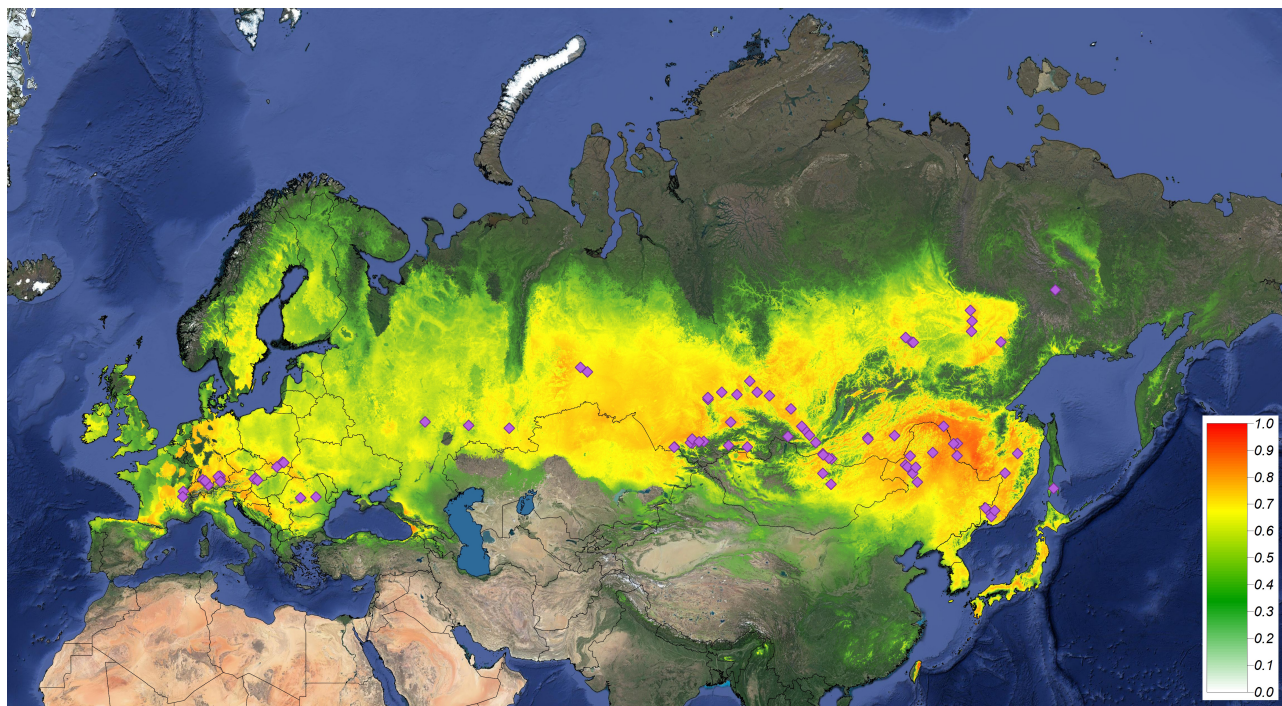
We analysed the results from three types of models: past (LIG, LGM and Mid-Holocene), present and future (two time periods (2050 and 2070) and four RCPs (+ 2.6, + 4.5, + 6.0 and + 8.5 W/m<sup>2</sup>)). The AUC values for the individual models are summarised in table 1. For all of the models, the training and test AUC values were significantly different from random. A jackknife test (refer to Data S1 for the details and Maxent outputs) showed that the mean temperature of wettest quarter (Bio08) was the environmental variable that was the most informative by itself and had a significant amount of information that was not contained in the other variables. In the areas we studied, the wettest quarter covered June to August, which was also the warmest quarter of the year (average 16.4°C). Therefore, the precipitation of warmest quarter (Bio18) was also significant and the average rainfall for the studied areas from June to August was 255 mm/m<sup>2</sup>. The precipitation in the driest month (Bio14) had the least significance among the selected variables but was important for the models – the driest month in these areas was February with an average rainfall of 18.4 mm/m<sup>2</sup>. This makes sense because we are talking about upland and mountainous areas and therefore winter is the driest time of the year. Isothermality (Bio03) fluctuated around 0.25%, which meant that the ratio of the temperature's mean diurnal range was small compared to the annual range. In turn, the annual mean temperature (Bio01) fluctuated from -10.5 to 10.2°C.

### Ecological niches and potential distribution

All of the resulting maps show the median of the output grid of 10 model replicates. For the present model (Fig. 1), the results suggest that the most suitable areas for *P. (P.) carpathicus* are located in China (the Inner Mongolia Autonomous Region, the Heilongjiang and Jilin Provinces), North Korea, South Korea, the islands of Japan, Russia (Primorsky Krai, the Jewish Autonomous Oblast, the southern part of Khabarovsk

Krai, Amur Oblast, Zabaykalsky Krai, the Republic of Buryatia, the southern part of Yakutia, the Irkutsk Oblast, the southern part of Krasnoyarsk Krai, the central part of the Tyva Republic, the northern part of the Altai Republic, the Republic of Khakassia, the Kemerovo Oblast, Altai Krai, the Novosibirsk Oblast, the Tomsk Oblast, the Omsk Oblast, the Tyumen Oblast, the southern part of the Khanty-Mansi Autonomous Okrug-Yugra, the Kurgan Oblast, the Sverdlovsk Oblast, the Chelyabinsk Oblast, the Orenburg Oblast, the Republic of Bashkortostan), Mongolia (mainly the

north-western provinces: Dornod, Sükhbaatar, Khentii, Govisumber, the northern part of Dornogovi, Töv, Ulaanbaatar, Selenge, Darkhan-Uul, Bulgan, the Orkhon and Uvs province – around the Uvs Lake Basin, a part of the Great Lakes Depression), Kazakhstan (the East Kazakhstan Region, the northern part of the Karaganda Region, the Pavlodar Region, the Akmola Region, the North Kazakhstan Region, the Kostanay Region) and Georgia (in particular, the Megrelia-Upper Svaneti, Guria and Imeretia regions and Abkhazia). In Europe, the most suitable areas are mainly located in upland



**Fig. 1.** Model result of a potentially suitable ecological niche for *Polymerus (Pachycentrum) carpathicus* (Horváth, 1882) in Eurasia at present. Diamonds represent the currently known sites of occurrence of species. The colour scale shows the probability of a suitable ecological niche.

**Table 1.** Model results of the AUC values for different periods

Type of model		AUC value	Standard deviation
Past	LIG	0.914	2.9%
	LGM	0.917	3.5%
	Mid-Holocene	0.915	4.6%
Present		0.917	3.1%
Future	2050 (2.6)	0.915	3.5%
	2050 (4.5)	0.914	3.5%
	2050 (6.0)	0.916	3.2%
	2050 (8.5)	0.914	3.8%
	2070 (2.6)	0.913	3.5%
	2070 (4.5)	0.912	2.8%
	2070 (6.0)	0.915	3.3%
	2070 (8.5)	0.914	3.0%



areas – the Carpathian Mountains (the Czech Republic, Slovakia, Poland, Ukraine, Romania), the Dinaric Alps (Slovenia, Croatia, Bosnia and Herzegovina, Serbia), the Rhodope Mountains (Bulgaria), the Alps (Switzerland, Liechtenstein, Germany, Austria), the Alpine foothills, the Bavarian Alpine Foreland, the Pyrenees (on the French side – the Pyrénées-Atlantiques, Hautes-Pyrénées and Ariège departments), the Massif Central (France), Vosges (eastern France) and the Ore Mountain Range (the border between Germany and the Czech Republic), but not in high mountainous sites. In addition to the upland areas, the model also suggests favourable environmental conditions in the area of the Paris Basin (France), Condroz (Belgium), Ardennes (Belgium and Luxembourg) and the North German Plain.

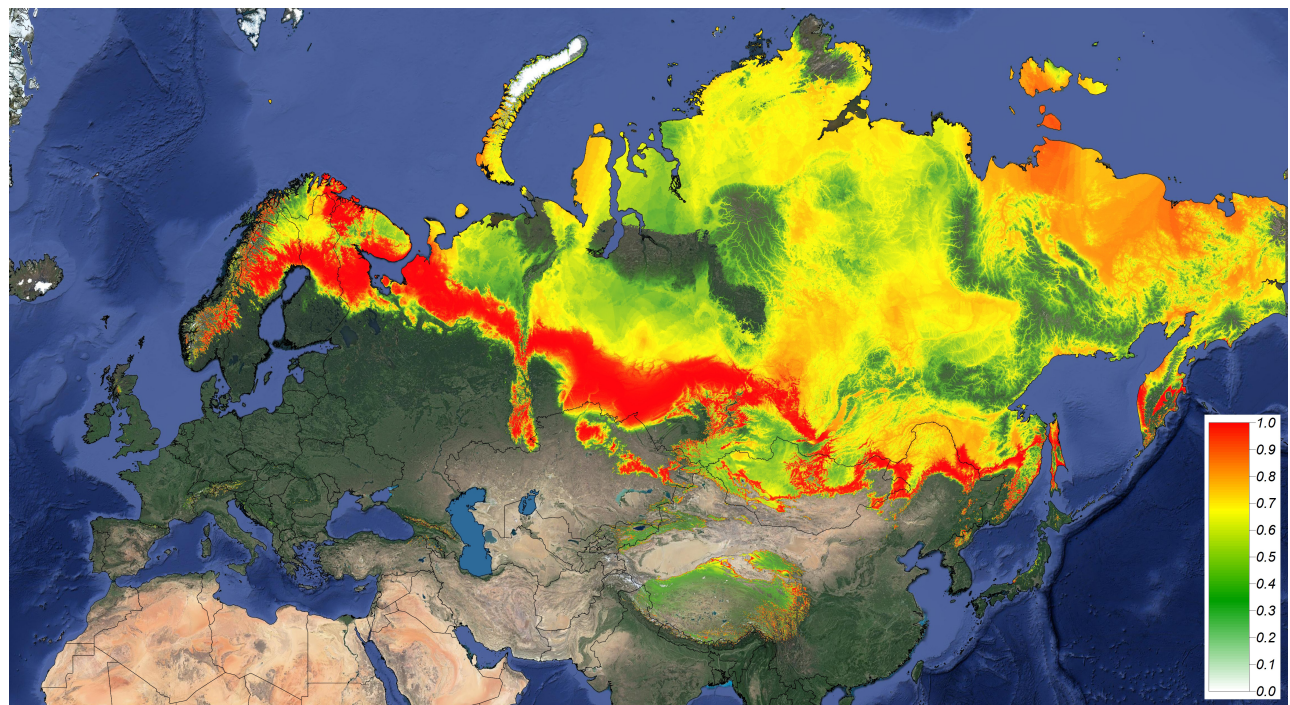
For the past models, during the last interglacial, it is clearly shown that favourable climatic conditions for this species may have occurred in the belt that stretches from the northern part of modern-day Scandinavian Peninsula through Russia and Mongolia into the northern part of modern-day China (Fig. 2). The model also indicates areas of modern-day Yakutia, Chukotka and Kamchatka Peninsula. However, considering the current distribution of the representatives of the species, the geographical place of origin was probably located in the part of modern-day Russia that borders Kazakhstan and Mongolia.

In turn, during the last glacial maximum, the

suitable environmental conditions were in the south and southwest (Fig. 3). The right temperature and humidity prevailed there, which is why numerous boreal species could have survived in the places that were located in the foreland of the ice sheet. This refers mainly to the host plant of *P. (P.) carpathicus* – *Galium boreale*. In Europe (the Netherlands, Germany, Slovenia, Austria, the Czech Republic, Poland, Slovakia, Hungary, Ukraine, Romania, Moldova), populations of *G. boreale* probably developed and with them, the range of *P. (P.) carpathicus* expanded.

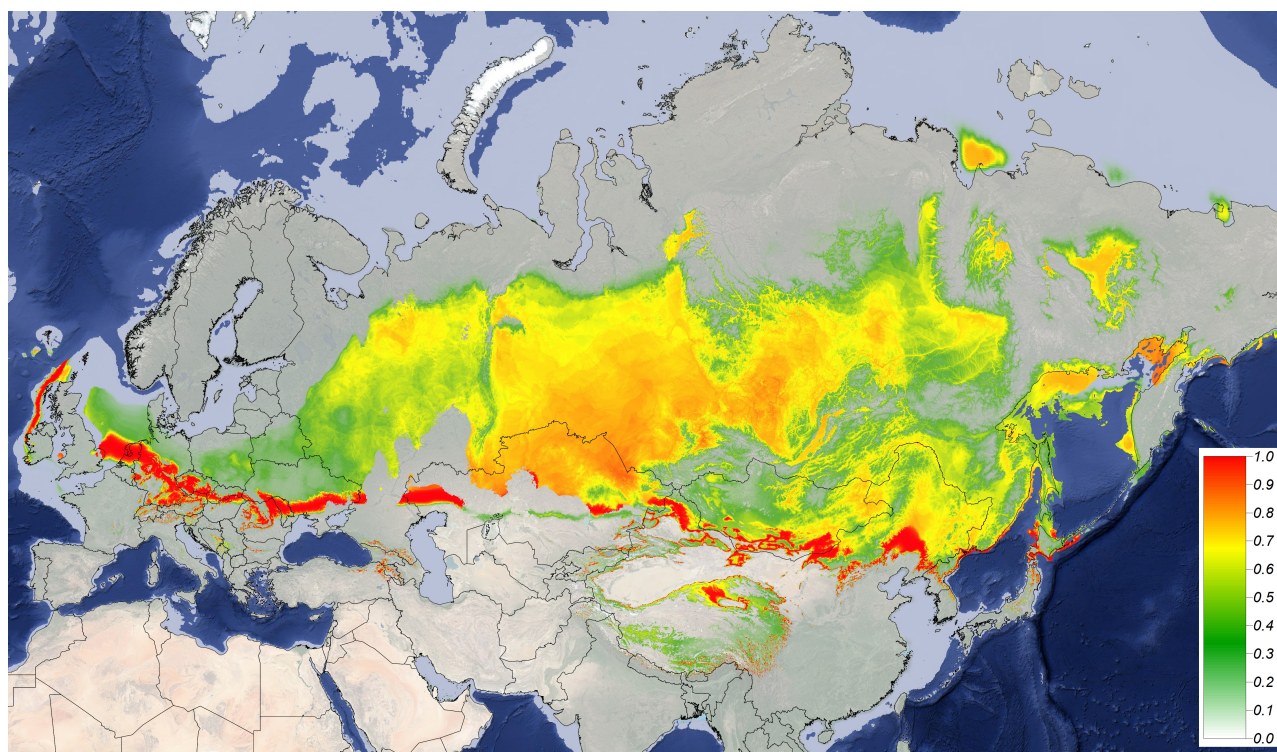
However, during the Mid-Holocene, the range of climatically suitable areas almost coincided with the area that was designated during the last glacial maximum (Fig. 4). However, as has been reported in studies on plant ranges (e.g., Castroviejo et al. 2007; Dimopoulos et al. 2013; Ruhsam 2005), the range of *G. boreale* in Europe has not shrunk so drastically in the last seventy years, and this plant has certainly survived in many refuges. After the last glacial maximum, both *P. (P.) carpathicus* and its host plant gradually expanded their ranges.

*Polymerus (P.) carpathicus* appears to be a species that is sensitive to climate change. All of the results of the model for the future climate scenarios, regardless of RCP concentration, indicate that there was a considerable reduction in the niche and a shift in the potential range to the far north (Fig. 5). Areas

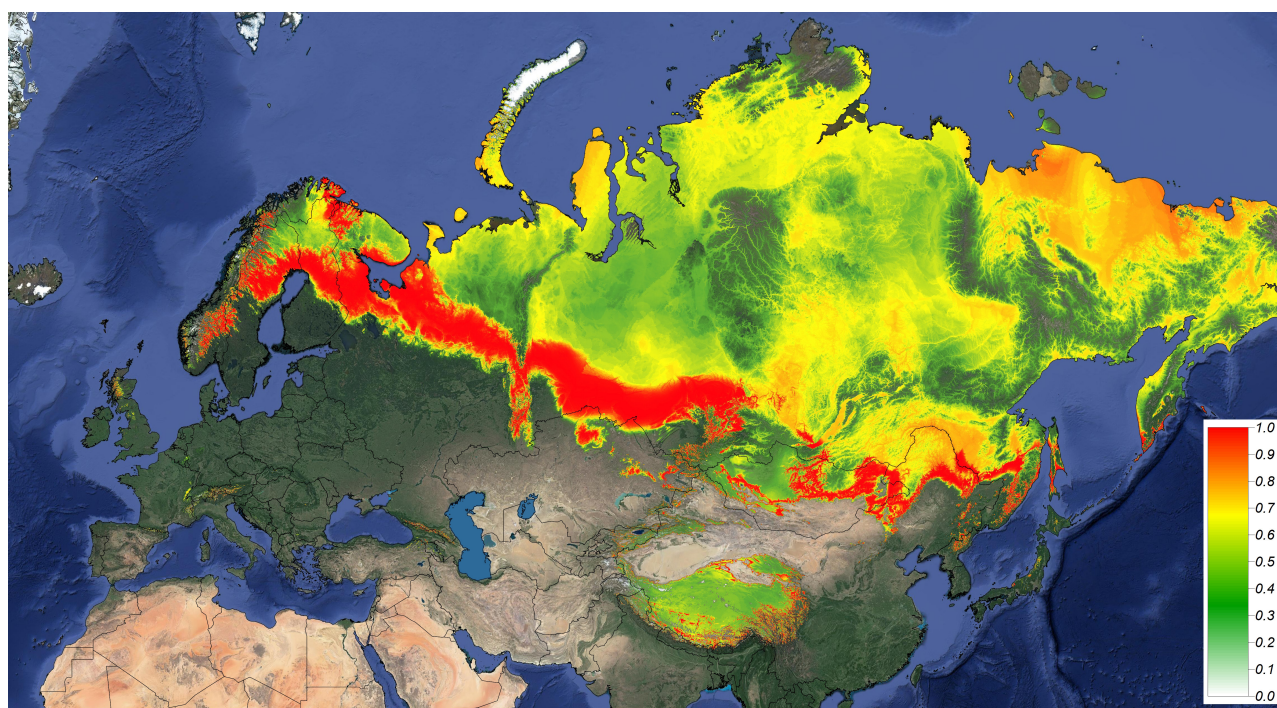


**Fig. 2.** Model result of the potentially suitable ecological niches for *Polymerus (Pachycentrum) carpathicus* (Horváth, 1882) in Eurasia during the last interglacial. The colour scale shows the probability of a suitable ecological niche.



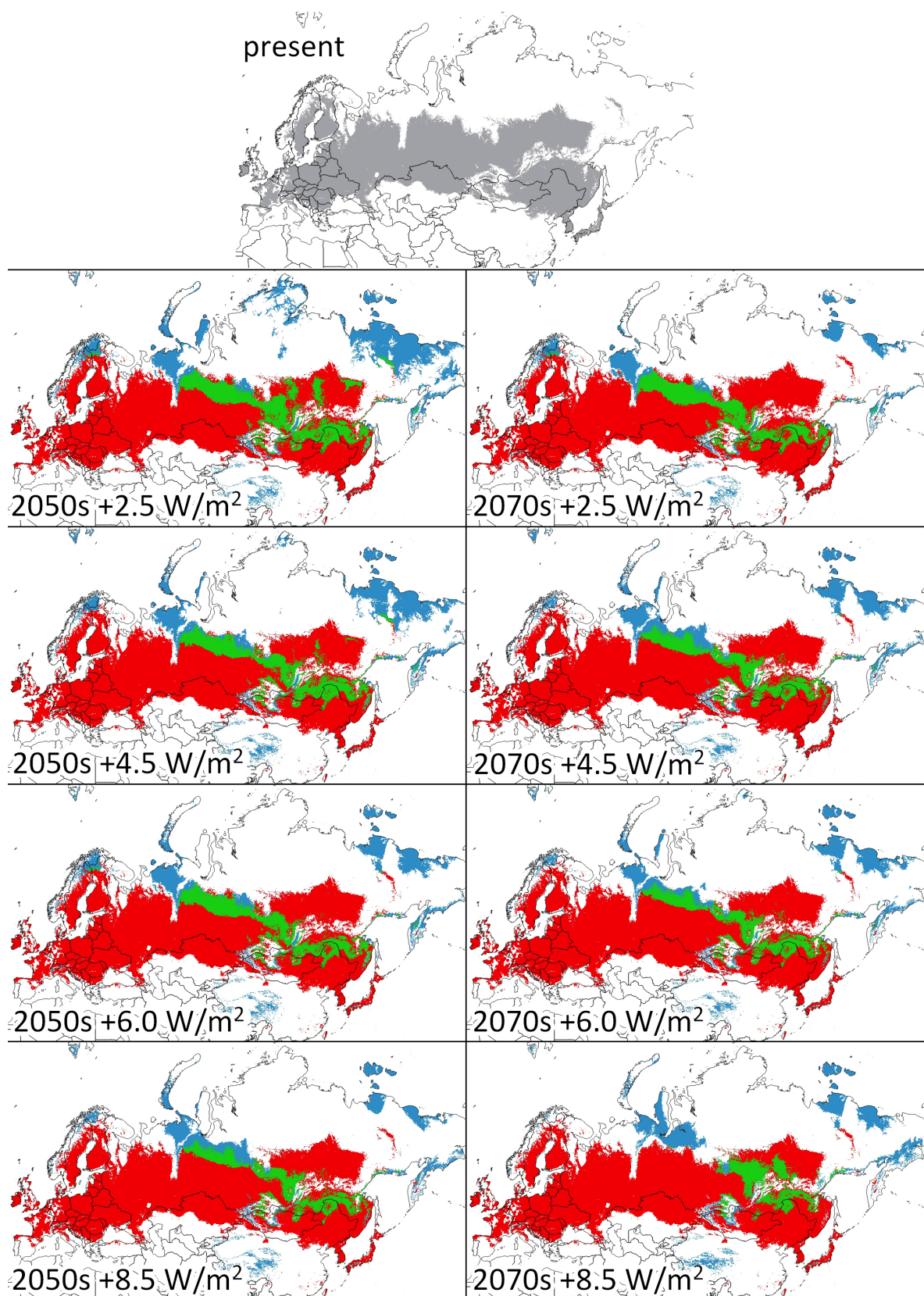


**Fig. 3.** Model result of the potentially suitable ecological niches for *Polymerus (Pachycentrum) carpathicus* (Horváth, 1882) in Eurasia during the last glacial maximum. The colour scale shows the probability of a suitable ecological niche. The bright area shows the boundaries of the ice sheet.



**Fig. 4.** Model result of the potentially suitable ecological niches for *Polymerus (Pachycentrum) carpathicus* (Horváth, 1882) in Eurasia during the Mid-Holocene. The colour scale shows the probability of a suitable ecological niche.





**Fig. 5.** Predicted future (suitable/stable – green, lost – red and gained – blue) habitats for *Polymerus (Pachycentrum) carpathicus* (Horváth, 1882) in Eurasia. Future predictions under all four RCP scenarios (+2.5, +4.5, +6.0 and +8.5 W/m<sup>2</sup>) for the 2050s and 2070s.

such as those that are proposed by the results of the Mid-Holocene model were also determined. Thus, the increase in temperature has forced the representatives of the species *P. (P.) carpathicus* to move to the higher parts of the mountains as well as northward into a cooler climate.

### Climatic preferences

The potential ecological niches of *P. (P.) carpathicus* were compared with the Köppen-Geiger climate classification to determine the species' possible climatic preferences. An analysis of the climate types in the known locations of this species indicates that it prefers continental climates: humid continental and subarctic (boreal) (see climatic diagrams in Data S1). The warm summer subtype was dominant (Dwb, Dfb) – the average temperatures in the warmest month are below 22°C (71°F), while in the coldest month, they are usually well below -3°C (27°F), so winters are cold. Within the second dominant subtype, the subarctic climate, winters are long, dry and temperatures often fall below -50°C (-58°F), while in the short summer, the temperature may exceed 26°C (79°F). During this time, it is also characteristic that for five to seven months, the average temperature is below freezing.

### Biomes and zoogeographical regions

Among all of the sites of occurrence that were examined, 31% inhabited temperate grasslands, savannas and shrublands. Other inhabited areas

included temperate broadleaf and mixed forests (24%), boreal forests/taiga (21%), temperate conifer forests (16%) and flooded grasslands and savannas (7%) (Fig. 6). This species is strongly associated with forest areas and grasslands and savannas (for more information, see Table S3). This is not surprising because the host plant of this species, *G. boreale*, grows in grassy places, forests and meadows (Budd et al. 1987).

### Key to identifying the species of the subgenera *Pachycentrum* and *Polymerus* that occur in Poland

- 1(2). Legs and frequently base of cuneus entirely black .....  
..... *P. (Pachycentrum) carpathicus*
- 2(1). Tibiae yellow or brownish yellow with dark rings in basal half,  
cuneus usually yellow at base ..... 3
- 3(4). Femora black, antennae black or black-dark brown .....  
..... *P. (Pachycentrum) nigrita*
- 4(3). Femora in apical part yellow with dark spots or rings before  
apices, antennae bicolour, yellow-black .....  
..... *P. (Polymerus) holosericeus*

The key enables the three species that occur in Poland as well as widely in Europe to be distinguished (Fig. 7). It covers these two subgenera because *P. (Pachycentrum)* was separated from *P. (Polymerus)*. The distribution of the three species of the genus *Polymerus* in Poland (Fig. 7) (Gierlasiński and Tazsakowski 2013–2021) are also presented because the first locations are identified for *P. (P.) carpathicus* (Fig. 7) – Eastern Beskidy Mts.: Bednarka [EV29]: 27.08.2013, 1 ex., Kąty [EV39]: 22.07.2013, 1 ex.

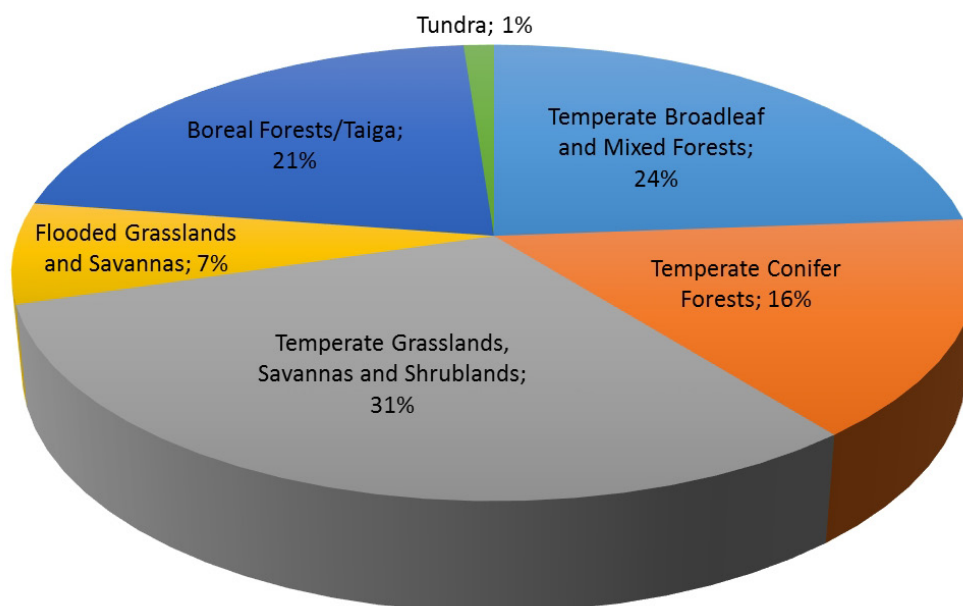


Fig. 6. The percentage share of the representatives of *Polymerus (Pachycentrum) carpathicus* (Horváth, 1882) in the different biomes.

## DISCUSSION

The locus typicus of *Polymerus (Pachycentrum) carpathicus* is located in Kežmarok, Slovakia (Horváth 1882). This city is located close to Poland, which makes it surprising that this species was not collected in Poland thus far despite the close geographic proximity. However, the geographic origin of *P. (P.) carpathicus* is not known, based on the range of occurrence and habitat of its representatives (which also distinguishes it from other representatives of this genus), and therefore it is possible to speculate its region of origin.

Because there is no natural biogeographic boundary in the east and south between Europe and Asia, many animal and plant species can move freely and expand their range (e.g., Smith et al. 2006; Lang

et al. 2007; Suzuki et al. 2008; Conolly et al. 2012). Therefore, based on the modelling results, it can be concluded that *P. (P.) carpathicus* is a species of an Asian origin. This is indicated by the favourable conditions that occurred during the last interglacial when about 20000 years BCE, most of north-western Europe was covered by a large ice sheet, and over time, many species began to expand their ranges *via* rapid migration (Huntley and Birks 1983). The distribution of phytophagous insects, especially monophagous species such as *P. (P.) carpathicus*, depends mainly on their host plants and natural communities. Therefore, distribution predictions for various insect species, whether in the past or future, coincide with the distributions of their host plants. That is why the data about the prehistoric record of pollens are so important and are the primary

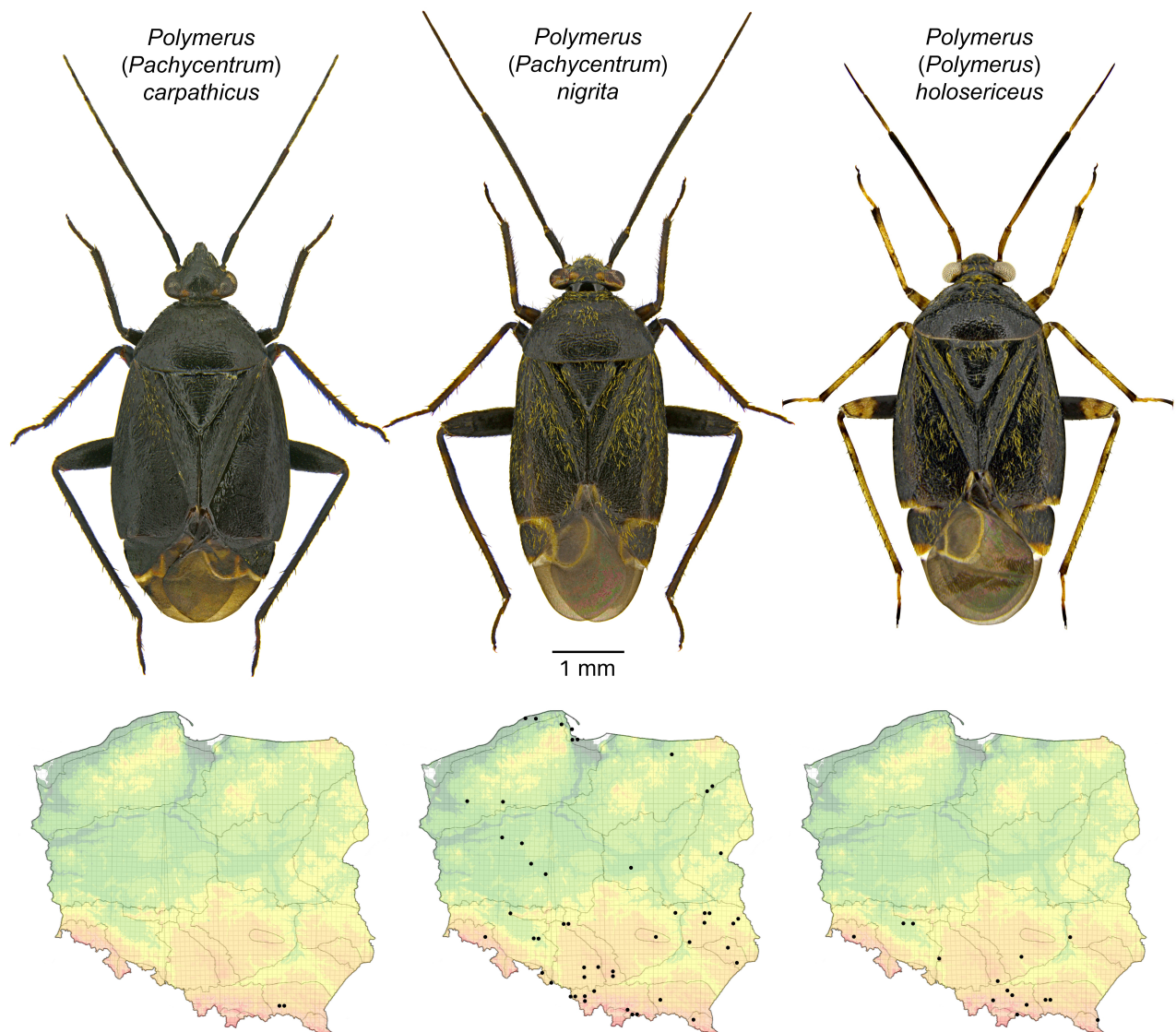


Fig. 7. Dorsal habitus and distribution of the examined species in Poland.



source of information about the postglacial migrations (Huntley and Birks 1983).

Based on the results obtained in this study, it can be assumed that because of glaciation and the presence of the ice sheet, representatives of *P. (P.) carpathicus* could have slowly been “pushed” from central Asia towards the south and southwest. The model results from the period of the last glacial maximum clearly show the influence of the ice cover on the shift of favourable climatic conditions to the south (Fig. 3). Therefore, this species may have appeared in Europe as a result of migration. This direction of its expansion also seems to be correct because of the niche it occupies. *Galium boreale* is a ubiquitous plant – its range includes the subarctic and temperate zones of the Northern Hemisphere. However, the areas that *P. (P.) carpathicus* inhabits are mostly mountain areas. Perhaps, both species spread to Europe through Asia and during periods of full glaciers, they survived in many different areas of refuges in Europe. For most nemoral and boreal plants, their current distribution was laid in the glaciated area during the last glacial maximum or in habitats such as the tundra or steppe (Starkel 1988; Tarasov et al. 2000; Binney et al. 2017). Research that deals with the reconstruction of plant communities for the glaciation period, which is based on palaeozoological and paleobotanic analyses plus the modelling of vegetation distribution, indicate that the conditions prevailing during the LGM in Central Europe guaranteed the survival of boreal temperate species (Ralska-Jasiewiczowa et al. 2004; Svenning et al. 2008; Fløjgaard et al. 2009). Thus, *Galium boreale* could have freely expanded its range in this area, thereby creating suitable habitats for *P. (P.) carpathicus*. During the retreat of the glacier, *G. boreale* spread into both the highlands and the lowlands, but the individuals representing *P. (P.) carpathicus* remained in the mountainous areas where their refugia were located. One of these geographically extensive places, where favourable climatic conditions prevailed even during the period of maximum glaciation, was the area of the Carpathians Mountains. This is where Central and Northern Europe’s postglacial colonisation began (Hewitt 1996 1999; Bilton et al. 1998; Provan and Bennett 2008). The Alpine refugium also seems to be important for the current distribution of representatives of *P. (P.) carpathicus* in Europe. On the way to Europe, on the other hand, the refugium of the southern part of the Ural Mountains and the Russian Plain (also known as the Eastern European Plain) could have been significant as it was for many other already documented species (e.g., Hewitt 1996; Bilton et al. 1998; Bachura and Kosintsev 2007; Svenning et al. 2008; Markova 2011).

The models for future climatic conditions, which assume an increase in CO<sub>2</sub> concentration and temperature (The Intergovernmental Panel on Climate Change 2007), indicate that the suitable niches for *P. (P.) carpathicus* will be drastically reduced. This is quite similar to the results that we obtained for the Mid-Holocene and the last glacial maximum. This suggests that this species is sensitive to climate change and the areas that it inhabits undergo constant but long-lasting changes. In the high mountains, there are different buffer zones that somehow protect species against extreme heat stress, especially during climate changes (Shoo et al. 2010). However, *P. (P.) carpathicus* is not only a high-mountain species. Therefore, it may be particularly exposed to temperature increases in the lower parts of the mountains. These changes will also affect refuges, which will be among the first to suffer local climatic loads (Razgour et al. 2013). Publications about new localities of this species are rare, although it seems that it might occur over a larger area than we know as yet. However, the results of our models show that representatives of *P. (P.) carpathicus* may not have a chance to widen its niche as the current niche appears to be shrinking.

Of course, our theory requires confirmation by further research, especially molecular research. Performing genetic analyses to compare the genes of individuals from Asia and Europe could certainly indicate what the relationships are. The patterns of distribution and migration in the past are fundamental in determining the modern structure of the intraspecific genetic variation in the geographical space (Hewitt 1996).

## CONCLUSIONS

*Polymerus (Pachycentrum) carpathicus* is a species that prefers ecological niches that are located in the highlands and mountains. An analysis of its distribution indicates a disjunctive range, but this could be due to a lack of data. Ecological niche modelling methods that were based on the literature data on the occurrence of this species were used. This enabled us to obtain new and valuable information about the potentially suitable habitats, the possible range of its distribution and its climatic preferences. An analysis of the results suggests that this species, despite the fact that the species name indicates a European origin, came to Europe from Asia due to postglacial migration. In turn, the currently occurring climate changes may adversely affect its future distribution. The model results show that the rise in global temperature will limit the favourable ecological niches of the species and that its range may

shift to the north.

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**Authors' contributions:** AB-N performed the ecological niche modelling and created the maps, analysed the occurrence data, analysed the climatic preferences of the species, and drafted the manuscript. AT performed the taxonomic analysis and collected the data on the occurrence of specimens, and drafted the manuscript. GG took the photographs and created the maps, and drafted manuscript. All of the authors read and approved the final manuscript.

**Competing interests:** AB-N, AT and GG declare that they have no conflict of interests.

**Availability of data and materials:** The data generated and analysed are available from the corresponding author. Additional materials such as the locations and model results as well as climate diagrams are available in the supplementary files.

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**Ethics approval consent to participate:** Not applicable.

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## Supplementary materials

**Data S1.** Maxent model outputs and climatic diagrams.  
(download)

**Table S1.** Details of all of the occurrence sites that were used in the Maxent model. (download)

**Table S2.** The results of the evaluation methods for the different Maxent settings. (download)

**Table S3.** Details regarding the assignment of the terrestrial ecoregions to the individuals of *Polymerus* (*Pachycentrum*) *carpathicus* (Horváth, 1882).  
(download)